2012 Project X Physics Study

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Neutron-antineutron oscillation vs nuclei stability

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Intro

Rabi Mohapatra presented theoretical motivations for neutron-antineutron oscillations.

$\Delta B = 2$ analog of the search for Majorana neutrino, $\Delta L = 2$.

Experimental limits on stability of nuclei set the range of interest for the free neutron oscillation time $\tau_{n\bar{n}}$.

Super-K (2011) $\tau(^{16}O) > 1.97 \times 10^{32}$ yr (Ed Kearns' talk)

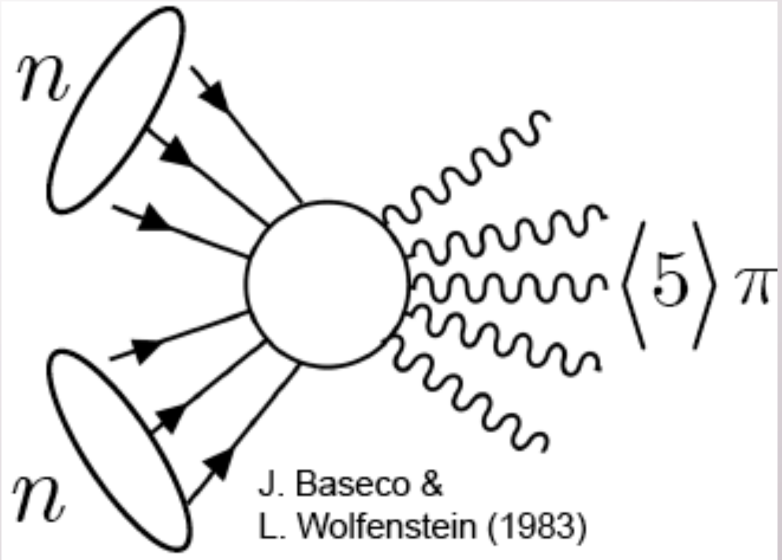
Theory, Friedman, Gal (2008), relates it to $\tau_{n\bar{n}}$,

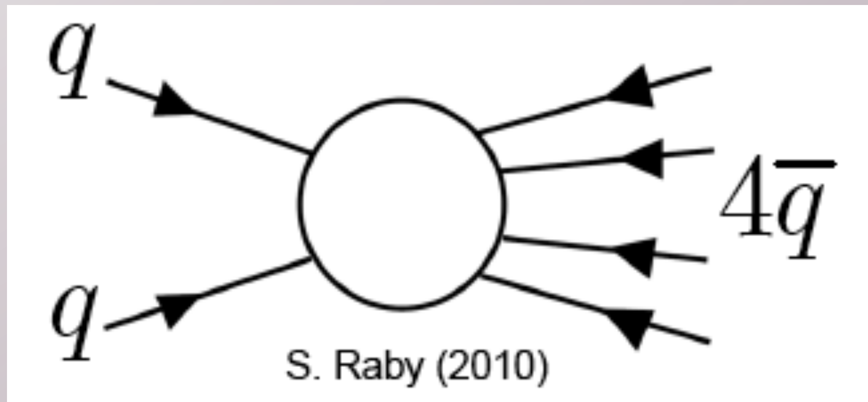
$$\tau_A = R\,\tau_{n\bar{n}}^2 \qquad R = 5 \times 10^{22}\ s^{-1} \qquad \tau_{n\bar{n}} > 3.53 \times 10^8\ \mathrm{s}$$

Free neutron ILL experiment (1994)

$$\tau_{n\bar{n}} > 0.86 \times 10^8\ \mathrm{s}$$

Number of extra mechanisms was proposed, in particular,





How much it affects the relation between $\tau_{n\bar{n}}$ and τ_A ?

To answer we try some independent approach based on Operator Product Expansion.

Operators ΔB=2

The operators contains two u quarks and four d quarks

$$\mathcal{O}_{\Delta B=-2} = uudddd$$

Each quark has color and spinor indices and could be left- or right-handed

$$q^i_{L\alpha}\,, \quad q^k_{R\dot\alpha}\,, \qquad i,k = 1,2,3\,, \alpha, \dot\alpha = 1,2$$

Color indices convoluted with two ϵ_{ijk} and spinor indices with $\epsilon^{\alpha\beta}$ or $\epsilon^{\dot\alpha\dot\beta}$.

Thus, there is quite a number of different operators which are different, in particular, by isospin

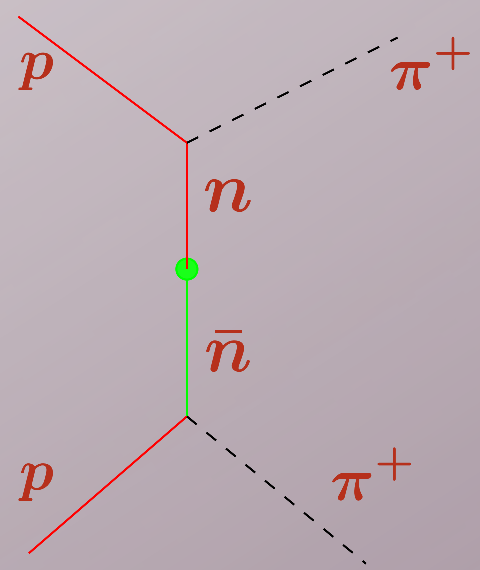
$$\Delta I = 1,2,3$$

The free $n \leftrightarrow \bar n$ oscillations are due to $\Delta I = 1$ only.

But for nuclei $\Delta I = 2, 3$ do contribute, so one can imagine the case of unstable nuclei and no $n \leftrightarrow \bar{n}$ oscillations.

Even simpler, only parity breaking part contribute to $\tau_{n\bar{n}}$ while the nuclei lifetime is affected by parity consvering processes.

Moreover, there are processes in nuclei involving the virtual $n \leftrightarrow \bar{n}$ transition which contribute to the nuclear instability.



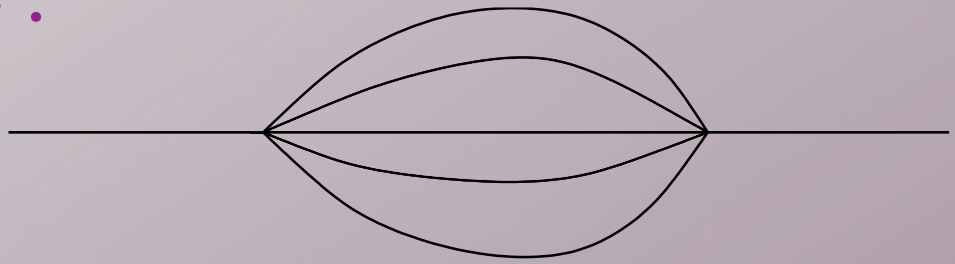
Estimate

Let us try to use some kind of duality to find a relation between the free $n \leftrightarrow \bar{n}$ oscillation and nuclear stability.

$$\langle \bar{n} | c^*_{\mathcal{O}} \mathcal{O}^\dagger | n \rangle = \epsilon \, \bar{u}^c_{\bar{n}} \gamma_5 u_n \qquad |\epsilon| = \frac{\hbar}{\tau_{n\bar{n}}}$$

where $\mathcal{O}^\dagger$ decreases B, $\Delta B = 2$.

Operator product expansion

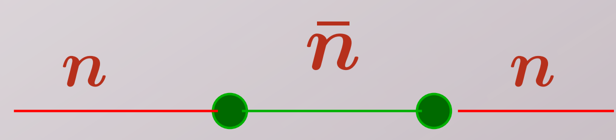


$$\int d^4x \, \mathrm{e}^{iqx} T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\} = c_q \, \bar{q}q + \ldots$$

The average over a nucleus A gives its lifetime τ_A

$$2|c_{\mathcal{O}}|^2 \mathrm{Im} \int d^4x \langle A | T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\} | A \rangle = \frac{\hbar}{\tau_A}$$

The average over neutron state



$$|c_{\mathcal{O}}|^2 \int d^4x\, \mathrm{e}^{iqx} \langle n|T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\}|n\rangle \sim \frac{|\epsilon|^2}{\Delta}$$

where Eucledian $q \sim \Delta$ is a relevant hadronic duality scale.

Taking $\langle A|\bar{q}q|A\rangle \sim A\,\langle n|\bar{q}q|n\rangle$ for the leading OPE term we get

$$\tau_A = R\,\tau^2_{n\bar{n},n} \quad R = \frac{\Delta}{A\hbar}$$

For ^{16}O and an educated guess for $\Delta = 0.5\ \mathrm{GeV}$

$$R = 4.7 \times 10^{22}\ s^{-1}$$

what is close to the result obtained by Friedman, Gal (2008).

The inclusive approach does include all the mechisms.

Conclusion

While, probably, more theoretical studies are needed there is no much room for changing the relation between nuclear disappearance lifetimes and free neutron-antineutron oscillations.

What is the theoretical accuracy? Needs more work.